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Competence Development
Learning by Problem Solving

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KOGNITIONSVETENSKAPLIG FORSKNING

Cognitive Science Research

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Abstract

On the basis of a dialogue between two students engaged in solving a problem, it is argued hat the students differ in their problem-solving capabilities, that is, they reduce the complexity of the situation in different ways. It is also argued that the students do not exhibit the same form of competence. In other words, they make sense of the complex situation in different ways. Further, it is maintained that existing theories are able to explain different aspects of the problem-solving process, and by that competence. However, no single theory encompasses all the aspects. Therefore, a more comprehensive theory is proposed. This theory encompasses the notion that the person by means of ideas is able to consider and anticipate problem-solving operations, and in doing so, the person is in control of the problem-solving process, that is, displays competence. More precisely, the person is in control by means of four processes: efficacy, which is the degree to which the person experiences the feeling of control of the problem-solving process itself; achievement, which is the degree to which the person experiences that he or she is approaching the goal; ruggedness, which is the degree of difficulty the person feels he or she has to overcome in order to solve the problem; and finally availability, which is the degree to which the person feels he or she has access to vital resources. Using this frame of reference, an interpretation of the two students' problem-solving process is carried out. Finally, it is suggested that it is possible to apply catastrophe theory in order to make a model of problem-solving behaviour.

What did you learn in school today?

In a Danish upper secondary school class, a group of students is trying to solve the problem of resistance in wires (Ohm's law) (Bang, 1996). Having measured the resistance in three different wires, Ann advances the hypothesis that the resistance decreases proportionally to the thickness of the wire. Her hypothesis is based on an analogy between water flowing through pipes and electrons flowing through wires. It is, so to speak, easier to push the water/electrons through a thick pipe/wire than a narrow one. Her two group mates are of a different opinion, but they accept Ann's hypothesis at the beginning of the following problem-solving process, which develops into a dialogue between Ann, Cathy and the teacher.

Cathy: So, the thinner (the wire), the greater (the resistance).
Teacher: Yes. Can you explain it a little more in detail? What happens if you have a wire that is half as thick?
Cathy: Let's discuss it...Ann, just listen...the thickness, if it is half as thick, do you think the resistance will be twice as big, or not, is it...?
Ann: Umm...I really don't know...we have a different understanding.
Teacher: What is it then?
Cathy: Well, it's just that before we thought that the resistance would be greater the thicker it was. Then...it could be that there are half as many electrons going through a wire that is half as thick, couldn't we also say that it's inversely proportional?
Teacher: So, after careful consideration, you have come to the conclusion that it (resistance) is inversely proportional to the thickness of the wire?
Cathy: Umm...yes, right? It is half as strong and twice as thick.
Ann: So the greater the resistance--yes, that's true, it is inversely proportional, yes!
Teacher: Let's say that's what you think. And that is the sketch, there, that shows that? (points to drawing) What do you call that kind of graph -- can you remember we talked about it yesterday?
Cathy: So, we just need one divided by the thickness (1/thickness).
Ann: The resistance decreases with the thickness.
Cathy: That is to say that the thinner it is, the less resistance there is...the thicker it is?
Ann: The thicker it is, the less the resistance, *c'est vrai*! That was exactly what I meant!
Cathy: That was also what we said.
Ann: Was it...you agreed with me?
Cathy (giggles): That was what we drew, it was nice. (on the first paper, where they summarised before the introduction, before the experiment)
Ann: Yes, in that way it's easier for the electrons to come through.
Cathy: The thicker it is, the more electrons can come through...if it is thin, maybe only one can come through at a time.
Ann: Yeah, water...so it can also come through faster, the thicker the pipe is, right...I think you can compare it with that...that's what they do in the old school anyway (secondary school).
Cathy: But, like Jan (another student) said, it is harder to come through a straw than through a tunnel, right?

Here, the dialogue is interrupted as they make a measurement and a calculation.

Ann: No, they are *not* inversely proportional (resistance and thickness), unfortunately not.

Teacher: Have you concluded that now?
Cathy: Yes, after two measurements.
Teacher: Three, isn't that right?
Ann: Yes, we have three, and it is also good enough...that the resistance falls the thicker the wire becomes...and that goes for all three measurements...but it is *not* inversely proportional.
Cathy: No!
Ann: I wonder how that looks...?
Teacher: Try to make a drawing of such a wire...how would you draw it?
Ann: A wire?
Teacher: Yes.
Cathy: Well, don't we know that?...oh, a thick one.
Teacher: Yes.
Cathy: And a thin one.
Teacher: Try to draw a thick one and a thin one.
Ann (starts working): What do you want us to draw.
Teacher: That was the thin one, so try to draw a thick one.
Ann (draws): Is this what you mean?
Teacher: Yes, good... you have figured out now which one it is easiest for a stream to run through...good...now you have verified the idea about thickness...if you now look at the wire (in the drawing) from the end, it will be like this and not like that (little and big circle)? Now you have verified the thickness and found out that it isn't that that is interesting...
Cathy:...But...God!...yes, that could really be the case!
Ann:...This one...is four times as big...
Cathy: Every time the first one gets twice as small, the second one becomes...no...Ann, look...if this one is half as big as that one, the space becomes...four times as small...cause this is both twice as big this way and this way (horizontal and vertical. Comparison of the drawn fields).
Teacher: Aha!
Ann: We need to get hold of something that's called "r times pi" ...how is it now...circumference.
Cathy: Yes, "two times pi times r".
Teacher: That is the circumference. Yes, but the area is "pi times r to the second".
Cathy: Yes.
Ann: Well, that was also what I thought, I just couldn't remember the formula.
Cathy: That way.
Ann: Yes, let's try that...that r...we should have half of it (???) and set it to the second.
Cathy: What was the diameter?
Teacher: 0.25
Cathy: Yes
Ann: It is 0.125 (radius)...to the second...times pi...what should we use that for....to find the area of it, right?
Cathy: So I will multiply with it...(long pause)...I will put it in the memory (of calculator).
Teacher: Do you know what? I think you should do it carefully...make a graph in the place of, no...that is hard to see now when the others are coming into the room (the bell rang a little while ago, the class is over)...but I think you have a good idea now...at any rate, it's an idea worth going home to test, isn't it?
End of lesson.

It is evident that the two students both contribute to the problem-solving process, and that they reach some form of joint solution. However, although it seems as if they manage the situation in quite different ways, it is difficult to determine exactly how their problem-solving strategies differ. It is also questionable whether they obtained the same level of knowledge from the problem-solving process. To answer these questions, one must uncover the students' mental states generated during the process. If one could uncover the mental states of the students, and the processes which generated these states, it might be possible to reveal the hidden differences between the two students' problem-solving strategies and the different outcomes of the process.

Using the Perspective Text Analysis (PTA) (Bierschenk, Bierschenk, & Helmersson, 1996), it is possible to recreate and describe the developing mental states of the two students on the basis of their dialogue.

Perspective Text Analysis

Traditionally, texts are analysed in an intuitive way, that is, through the frame of reference of an interpreter, e.g. grounded theory. Using Perspective Text Analysis (PTA), it is possible to uncover the intentional message of the text-producer by means of the text-producer's own frame of reference (Helmersson, 1992).

PTA is based on the fundamental assumption that natural language production is governed by a specific language mechanism (Bierschenk, B., 1991,1993; Bierschenk, I., 1992,1999). Because the mechanism governs language production in a functional way, it is possible to reconstruct the mental structure which is generated in the process of text production, that is, PTA reveals the mental structure as a synthetic whole.

The PC-system 'Pertex' was developed to implement perspective text analysis. The results of a Pertex-analysis are presented in the form of a hierarchical cluster-tree, which shows how ideas and lines of thought are linked together into a synthetic structure (see p. 4). Thus, the outline of the structure of the mental state is generated solely by the PC-system. It is, however, the task of the text-analyser to describe the ideas expressed by the structure. In this process of describing, there is a certain degree of freedom, but the degree of freedom is constrained by the structure itself. If ideas are erroneously described, it is impossible to make the necessary synthesis. The ideas must connect at the level of synthesis. From the PC-system, it is possible to extract the figure-structure of the text, that is, the mental gestalt of the subject matter expressed by the text-producer, and the ground-structure, that is, the basis or the reasons of the figure-structure. In some texts, it is also possible to extract a goal- and a means-structure (ibid.). This is, however, not the case in the analysis presented below.

Description of the students' mental states

Ann

The entrance to the synthetic process (Figure 1) is the merging of the ideas 'search for physical connections' and 'doubt' into 'uncertainty concerning the object'. Apparently, Ann perceives that she has to look for physical object connections, but somehow she is in doubt, therefore the object of her search is blurred. In the next step, she is looking for a 'short cut', that is, she tries to point out the object, not by reflection, but by designation. Having pointed out the object, she cautiously affirms her viewpoint, but she is still uncertain. Therefore, she tries to frame the object in a reflective way. Although she has designated the object, she does

not jump to a conclusion. In order to eliminate her doubt, she introduces 'measuring of qualities', that is, she searches for relations between her understanding of the object, and the measurable qualities of the object. In doing so, she is, apparently, able to make a sort of confirmation, and therefore she gains some positive assurance concerning the established relation between her ideas and the object. She reaches a kind of conclusion. However, this conclusion is negated. She abandons her original idea. In the next step, the state of 'probing' is introduced as she searches for a new idea. She does not search randomly, but tries to establish a new state through the idea of a search-pattern, and thus she introduces the idea of 'goal-direction'. She realises that she has been hindered by her initial hypothesis. Now, it is time for methodical proceedings. In the next phase, she searches for a specific formula by means of which she can reach the goal through a specific operation. Apparently she finds such a formula, and thus, she gains control of the process. She does not solve the problem, but perceives that she is close to solving it.

Figure 1. Description of Figure

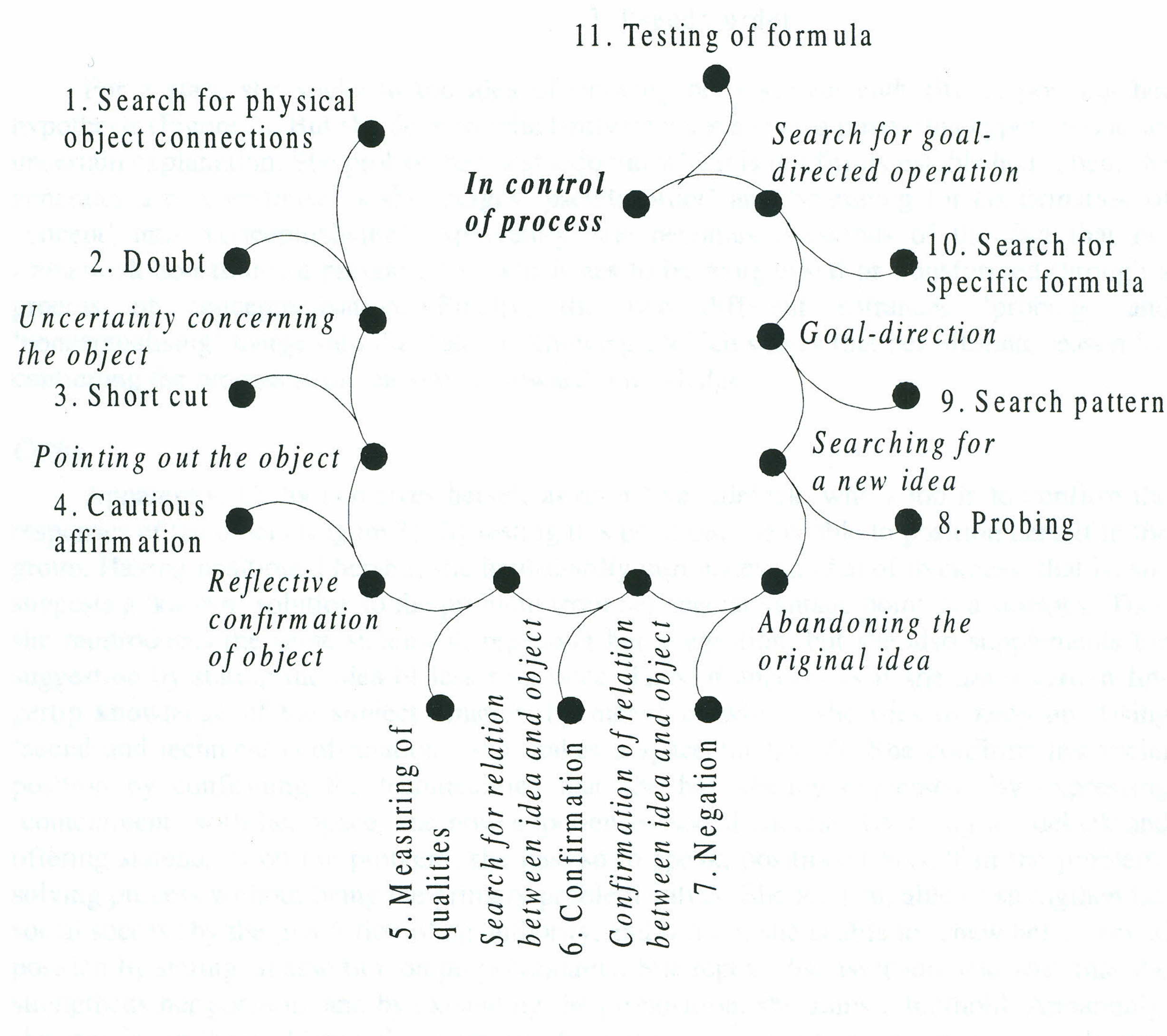
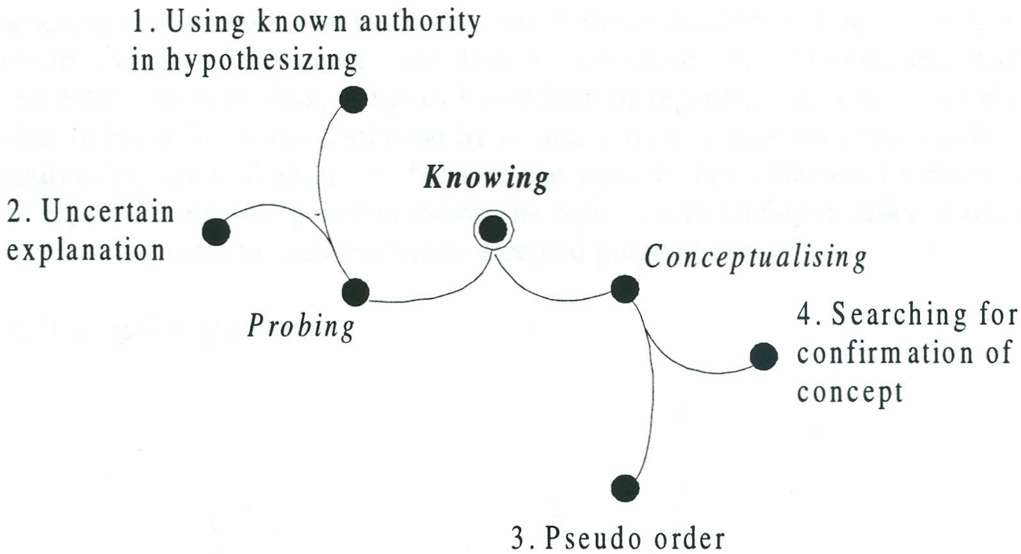


Figure 2. Description of Ground



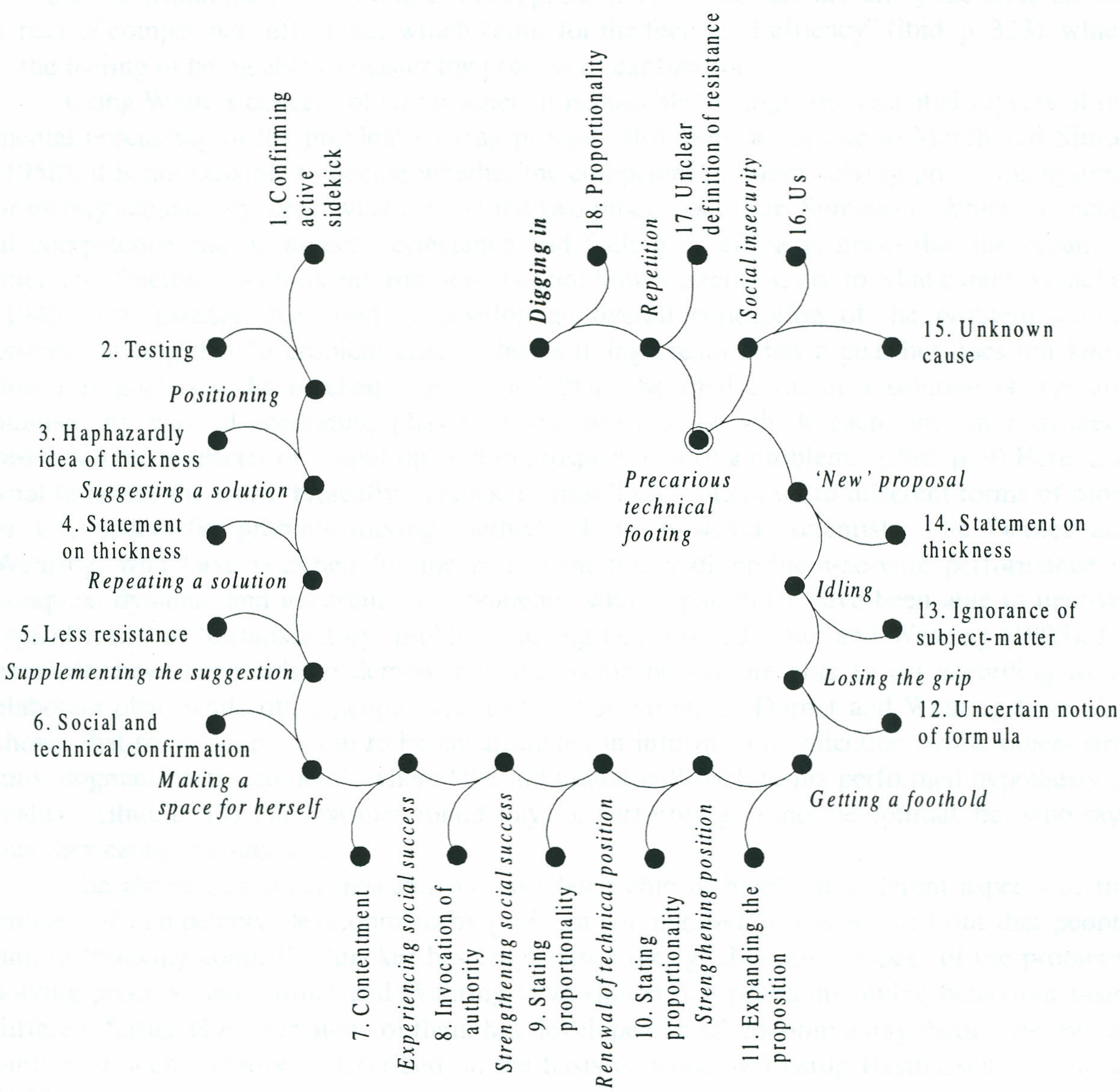
For a start, she sticks to the idea of drawing on a known authority in positing her hypothesis (Figure 2). But she does so reluctantly because she also posits this hypothesis as an uncertain explanation. She probes from a standpoint which is not firmly established. Then, she generates a new entrance as she merges 'pseudo order' and 'searching for confirmation of concept' into 'conceptualising'. Apparently, she becomes conscious of the fact that her framework constitutes a pseudo order which has to be reorganised or transformed through a process of conceptualisation. Finally, the two different entrances 'probing' and 'conceptualising' merge into the state of 'knowing', which shows that her ultimate reason for continuing the process is the movement towards knowledge.

Cathy

Apparently, Cathy perceives herself as an active sidekick, who's job is to confirm the responses of the others (Figure 3). By testing this position, she is able to position herself in the group. Having positioned herself, she haphazardly introduces an idea of thickness, that is, she suggests a 'known' solution to the problem from her special vantage point as a sidekick. Then she reintroduces the same statement, repeating her suggestion, but she also supplements the suggestion by stating the idea of less resistance. Thus, it appears as if she has a certain fingertip knowledge of the subject –matter, by means of which, she tries to keep up. Using 'social and technical confirmation', she makes a space for herself. She confirms her social position by confirming the technicalities that she has already expressed. By expressing 'contentment' with her space, she now experiences social success. By being a sidekick and offering statements on the problem, she has, so to speak, positioned herself in the problem-solving process without being the primary problem solver. She is, then, able to strengthen her social success by the invocation of an authority, and further, she is able to renew her technical position by stating an assertion on proportionality. She repeats the assertion, and with that she strengthens her position, and by expanding the proposition, she gains a foothold. Apparently, she remains in the problem-solving process by making a proposition, repeating and enlarging the proposition, and jumping to a new proposition. Unfortunately, she loses her grip because of her uncertain notion of a formula, and because of her ignorance of the subject matter; she is

idling. In order to transcend this untenable position, she reintroduces the statement on thickness, that is, she posits a 'new' proposal. Now a new opening in her thinking appears. Her mental state reveals that she realises that unknown causes are affecting the group. In consequence, she expresses social insecurity, which in conjunction with her statements put her on a precarious technical footing. She tries to strengthen her footing, but because the introduced definition is unclear, she goes into a loop of repetition. It is, so to speak, safer to repeat, than to break her social inclusion by stating a well thought-out, but unsafe, solution. This repetition becomes 'digging in', because she resumes her statement on proportionality. Instead of trying to solve the posed problem, she digs in, presumably in order to maintain her social position. It is safer to stick to already accepted propositions.

Figure 3. Description of Figure



It is evident that the two students' mental structuring of the problem-solving situation differs. Where Ann seems to proceed in a continuous reflective and ensuring manner, that is, she has transformed the posed task into a problem of her own and tries to solve it, Cathy, on

the other hand, seems to jump between different positions, or to stick to locked modes of thought. She is either roaming or digging in vis-à-vis the task. It also seems as if Cathy is more concerned with the social problem of maintaining her position in the group than in taking on the posed task. Maybe it is because of goal-interference that Cathy is unable to cope with the complexity of the situation, and because of that is forced into repetition. Thus, it appears as if the two students solve two different problems, and gain two quite different levels of knowledge by means of different problem-solving strategies. Further, it is striking that Cathy does not express any ground for her figure-structure. Apparently, she has no reason for her mental activity. However, in their own ways, both students interact effectively with their environment, which in the words of White (1959) means that they are competent. They are competent in the sense that they at least to some extent display a behaviour "that shows a lasting focalization and that has the characteristics of exploration and experimentation, a kind of variation within the focus" (White, 1959, p. 323). Thus, they are driven by the motivational aspect of competence: effectance which "aims for the feeling of efficacy" (ibid. p. 323), which is the feeling of being able to master the process of exploration.

Using White's concept of competence, it is possible to single out essential aspects of the mental processing of the problem-solving process. However, according to March and Simon (1958), it is not possible to decide whether the competent problem-solving process is optimal or merely satisfactory, or in what respect the two processes differ. Somehow, White's concept of competence and its aspects, effectance and feeling of efficacy, grasp that the organism interacts effectively with its environment, but not how it interacts, nor to what extent. Duncker (1945), for instance, has tried to develop an overall conception of the problem-solving process, stating that "a problem arises when a living creature has a goal but does not know how this goal is to be reached," (p. 1) and that "the final form of a solution is typically attained by way of mediating phases of the process, of which each one, in retrospect, possesses the character of a solution, and in prospect, that of a problem." (ibid. p. 9) Here, it is vital to notice the word 'typically'. Duncker himself calls attention to different forms of more or less successful problem-solving methods. It is, however, scientists, like Dörner and Wearing, who have searched for the inefficient forms of problem-solving performance in complex, dynamic and uncertain environments, who in particular have been able to uncover typical forms of 'unsatisfactory' problem-solving behaviour. Dörner and Wearing (1995), for example, have been able to demonstrate that some people are able to act according to an elaborate plan, while other people tend to 'muddle through'. Dörner and Wearing have also shown that some people seem to be encapsulated in information collection, while others sink into 'dogmatic entrenchment', where "the individual will stick to his performed hypothesis of reality." (ibid. p. 73) The last-mentioned ways of performing cannot be optimal, but who says that they cannot be satisfactory.

The above-mentioned researchers have been able to highlight different aspects of the process of competence development by problem solving. White has pointed out that people unfold 'tracking-control', Duncker has emphasised the 'goal-control' aspect of the problem-solving process, and Dörner and Wearing have shown that problem-solving behaviour takes different forms. However, none of them has developed an all-encompassing theory. Below, an outline of such a theory is described on the basis of work by Elstrup Rasmussen (1997a, b; 1998).[1]

[1] In the description of the theory, reflections on the founding of the theory in system dynamics, e.g. work by Kugler & Turvey (1987) and Prigogine & Stengers (1993), are omitted.

Making a model of competence development by problem solving

The theory of competence development by problem solving is based on the assumption that it is impossible to describe the performance of a living organism without concurrently describing the object that is subjected to the performance of the organism. The living organism, that is, the *intentional subject* (S_i), and the *subject-matter* (S_m) constitute an ecological *unity* and have to be analysed as a unity. It is also assumed that any ecological unity can be described as a process, that is, as an ecological activity, as well as an ecological structure (S_i/S_m), though not at the same time. Structure and process are two sides of the same coin, so to speak, and a coin must have two sides. The theory is thus based on the assumption that a specific natural stratum exists within the objective world which can be described structurally as an ecological unity (S_i/S_m) embedded in a material environment, and which also can be described as a specific ecological process, i.e. activity, in a material environmental world of physical motions and movements.

Viewed from the vantage point of the intentional subject, in this case the person, the fundamental process of the ecological unity can be described as a contralateral dynamism encompassing a transformation process and an information flow, or using structural terms, when enacting the subject matter, the subject perceives the subject matter. The structural form of the contralateral dynamism is formalised as ($S_i \equiv S_m$), where the symbol ($\equiv$) designates the enactment/perception relationship, which is called an operation. Thus, 'activity' and 'operation' refer to the processual and the structural form of the fundamental ecological unity, respectively.

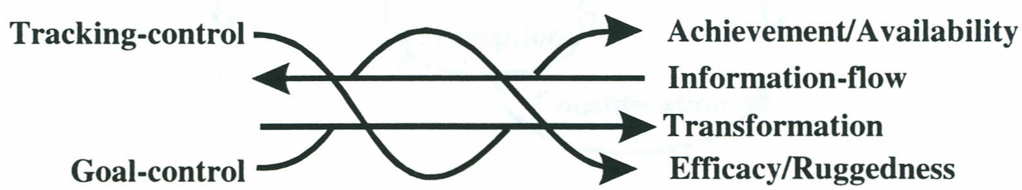
The contralateral process - activity - always constitutes differences, which can be described as complexity. If there are no differences between the transformation process and the information flow, no activity exists - the unity is at rest, so to speak. Considered structurally, the subject has to negotiate the set of differences between enactment and perception. In other words, at the structural level, any transformation-information dynamism constitutes a problem that has to be solved, which means that the set of differences must be reduced (i.e., complexity has to be changed into order). However, changing complexity into order takes time. Therefore, in order to maintain stability while solving problems, the subject must make sense of the complex situation in which problems are embedded. In other words, the subject has to express competence. If the person is unable to make sense of the situation and by that change complexity into order, he or she must flee or succumb.

At the phylogenetic level of human beings, the subject makes sense and negotiates problems by means of *ideas* synthesised into mental states, by way of natural language production. The person talks him- or herself through sense making, and by doing so, the person solves problems as shown in the introductory example.

However, the personal set of ideas constitutes an immense amount of mental degrees of freedom, that is, the set of ideas can be expressed via an infinite set of sentences. In order to structure an adequate set of ideas, expressed in the sense-making process which encompasses problem solving, the sense-making process is hypothesised to be constrained by two control processes: tracking-control and goal-control. It is further hypothesised that tracking-control and goal-control are split into conflicting parameters by the contralateral dynamism. Tracking-control is split into two conflicting control parameters: *efficacy and ruggedness.* Efficacy, posited by transformation, is a measure of the feeling of being the master of one's own action, while ruggedness, posited by the flow of information, is a measure of the feeling of the obstacles in the environment. Thus, tracking-control is the personal experience of being able to handle the route towards the goal. It is also hypothesised that goal-control is constituted by two conflicting control parameters: *achievement* and *availability.* Achievement, posited by

transformation, is a measure of the personal feeling of progress, while availability, posited by the flow of information, is a measure of the feeling of environmental abundance. Thus, goal-control is a personal experience of closing in on *a* (not *the*) solution. In general, achievement and availability can be described as the control parameters which are generated by and control the goal components of the problem-solving process, while efficacy and ruggedness can be described as the control parameters which control the tracking components of the problem-solving process. Where efficacy appears as the degree to which the person experiences the feeling of control of the problem-solving process itself, achievement appears as the degree to which the person experiences that he or she is approaching the goal. Ruggedness is the degree of difficulty the person feels he or she has to overcome in order to solve the problem, and availability is the degree to which the person feels he or she has access to vital resources. A model of the basic process of the ecological unit of analysis is shown in Figure 4.

Figure 4. The ecological unit of analysis described as a controlled contralateral process.

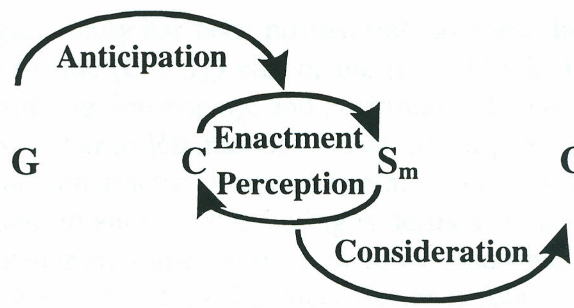


As mentioned above, the contralateral process, the transformation-information dynamism, always constitutes differences, that is, a problem. The measure of these differences is 'degree of complexity'. The greater the differences are between transformation and information, the more complex the situation is. Within this frame of reference, problem solving is defined as changing complexity into order, while competence is defined as the person's ability, by means of ideas, to generate a mental structure which can maintain the stability of the person in the face of complexity. Thus, competence means the ability of the person to make sense of a field of complexity defined by the activity; and being capable of making sense, the person is able to change the complexity of the situation into order by means of operations, that is, solve problems. The problem-solving process is controlled by the connection between the control parameters: goal-control, encompassing the conflicting processes of achievement and availability, and tracking-control, encompassing the conflicting processes of efficacy and ruggedness.

In order to provide a more comprehensive concept of personal competence and problem-solving capabilities, it is necessary to describe in a structural way the control of the transformation-information dynamism (as shown in Figure 5). Still viewing the process from the vantage point of the subject, the structure of the controlling parameters must encompass a position which indicates the subject as such, and that the subject is able to generate the feeling of being on top of the situation and closing in on a solution, that is, the subject must be able to occupy a position as generator (G in Figure 5). Thus, the position from which the subject is able to generate him- or herself as a constructor (C) who perceives and enacts the subject matter in order to reach goals by way of specified routes must be expressed. However, positing a constructor/subject-matter relationship implies that the generator position in time-space must be posited in an ante- as well as a post-position in face of the constructor/subject-matter relationship. In other words, the generator position appears as an anticipation function as well

as a consideration function relative to the constructor/subject-matter relationship. Thus structurally, the anticipation/consideration function expresses the goal- and tracking-control as a singular function. The anticipation/consideration function, comprehension for short, determines the constructor/subject-matter relationship, which is the goal- and track directed operation. This means that the subject appears as a split, but self-referential function. At the same time, the subject appears as a constructor who interacts with the subject matter, and as a generator who starts, directs, and tacks together operations.

Figure 5. The ecological unit of analysis described as a control structure.



Regarded as structure, goal- and tracking-control can be described as a relationship between an anticipation and a consideration function created by the generator position (see Figure 5). According to the model, the generator position directs another structure, which in functional terms can be described as an enactment/perception relationship between a constructor position (C) and a subject-matter position (S_m); that is, the operation is controlled by the generator. Therefore, if the subject only occupies the constructor position, the subject is not in control. For example, a person, who approaches a perceived table will automatically stop before she or he hits the table. However, in order to stop at a decided distance from the table, the person has to anticipate the table, consider and by that control the automatic walk-stop-operation.

This model is fairly abstract, but if it is read as a sentence, its concrete nature is revealed. The model could, for example, be described using the following text: 'The farmer' (G) decides (anticipation) that the 'farming trainee' (C) must chop (enactment/perception) 'the wood on the block with an axe' (S_m), and because of that, the farmer (G) thinks (consideration) that he will get (anticipation) a stack of wood (S_m) chopped (action/perception) by the farming trainee (C). In this sentence 'the farmer' takes the generator position, 'the farming trainee' takes the constructor position, and 'the wood on the block with an axe' takes the subject-matter position. The subject-matter position itself encompasses an ideal hidden operation in which the axe cleaves the wood in such a way that a purposeful result emerges.

This example shows that a set of ideas is put into a specific order, therefore the anticipation/consideration functions appear as first order parameters in relation to the set of possible ideas which could have been expressed. Thus, the two functions emerge in the sense making process itself in the form of order parameters. An "order parameter is created by the co-operation of the individual parts of the system (...) (In this case ideas: our remark). Conversely, it governs or constrains the behavior of the individual parts. This is a strange kind of circular causality," (Kelso, 1997 p. 8) in which the order parameters "move the system through

patterns (coherent collective states), but do not prescribe or encode these states." (ibid. p. 69) Thus, in structuring ideas by means of natural language, that is competence, two order parameters emerge, and the emerging order parameters constrain the structuring of the mental state into a problem-solving process, which takes the form of controlled operations.

The model (i.e., the ordering structure) can be described formally as $(G \equiv (C \equiv S_m))$-unity, which expresses the unity described as an anticipation/consideration relationship between a generator (G), and the enactment/perception relationship between the constructor (C) and the subject-matter (S_m) of the constructor. In this ordering structure, the anticipation/consideration relationship determines the unfolding of the constructor/subject-matter relationship.

Ideas as state-variables of the ecological unity

So far, the ecological unity has been posited only as form. In order to posit the unity as content, it is necessary for the $(C \equiv S_m)$ part of the $(G \equiv (C \equiv S_m))$-unity to encompass three types of processes: identifying, integrating, and positioning. In a co-operative way, these three processes generate ideas (Elstrup Rasmussen, 1994a, b). In general, identifying is defined as the process by which the constructor posits an operation in which one form of ideal subject matter becomes equivalent to another. Integrating is defined as the process by which forms of ideal forms of subject matter are joined into a new form. And finally, positioning is defined as the process by which some form of ideal subject matter is related to another form of subject matter.

As a whole, the three processes generate ideas which are prototypical expressions of the $(C \equiv S_m)$ component of the $(G \equiv (C \equiv S_m))$-unity. Ideas are the fundamental state-variables of the $(G \equiv (C \equiv S_m))$-unity, and, of course, the parts which give rise to and are controlled by the control parameters (tracking- and goal-control). Essentially, ideas are the tools of the person. An idea encompasses four components. The first component, generated by identifying, is called knowledge. In a specific $(G \equiv (C \equiv S_m))$-unity, that is, for a specific person, knowledge encompasses, for instance, the fact that 'cow' and 'horse' are identified in 'animal', where animal is the ID-card of the prototypical idea, so to speak. When a person puts 'animal' into words, the person expresses the identification of 'cow' and 'horse', although he or she only utilises the term animal. The second component, measure, is also generated by identifying. While knowledge is the qualitative result of the identifying process, measure is the quantitative. Any knowledge is accompanied by a measure that represents the importance which is attached to the represented subject matter. The third component, generated by integrating, is called insight. Insight is, for example, the realisation that 'egg' and 'oil' can be mixed into 'mayonnaise'. The insight component of an idea encompasses all the accumulated, that is, remembered integration results that the person has produced. The fourth component, generated by positioning, is called bearing. In language production, bearings are expressed by prepositions, by means of which, a person is able to arrange ideas in an utterance according to a framework. This framework, according to the theory of the synthetic language mechanism (Bierschenk & Bierschenk, 1986), encompasses a figure, a ground, a goal and a means component. In the sentence, 'The farming trainee must chop the wood (F) on the block (G) with an axe (M) for the winter (Go),' 'the wood' is positioned as figure, while 'the block' is positioned as ground, and 'an axe' and 'the winter' as means and goal, respectively. It is, thus, because of the positioning process that it is possible to organise any text-based mind expression into figure, ground, means and goal components, as shown in the analysis of the two students.

Ideas, which pick up the configuration of the information flow, are generated by operations, but they are assembled into stable mental structures by means of the generator function. Thus, the $(G \equiv (C \equiv S_m))$-unity encompasses the ability to make sense out of a field of complexity, that is, competence. However, the $(G \equiv (C \equiv S_m))$-unity is not able to generate just any idea. As a process, the generation of ideas is determined by the inherent difference within the contralateral transformation/information dynamism. Although the person intentionally creates mental structures, in general he or she does not invent reality. It happens, of course, but in that case the person is suffering from mental illness. However, the existence of delusions suggests that the $(G \equiv (C \equiv S_m))$-unity can generate ideas. The person is not simply a reactive system, but an intentional producer of meaning.

Competence: sense-making in embedded time

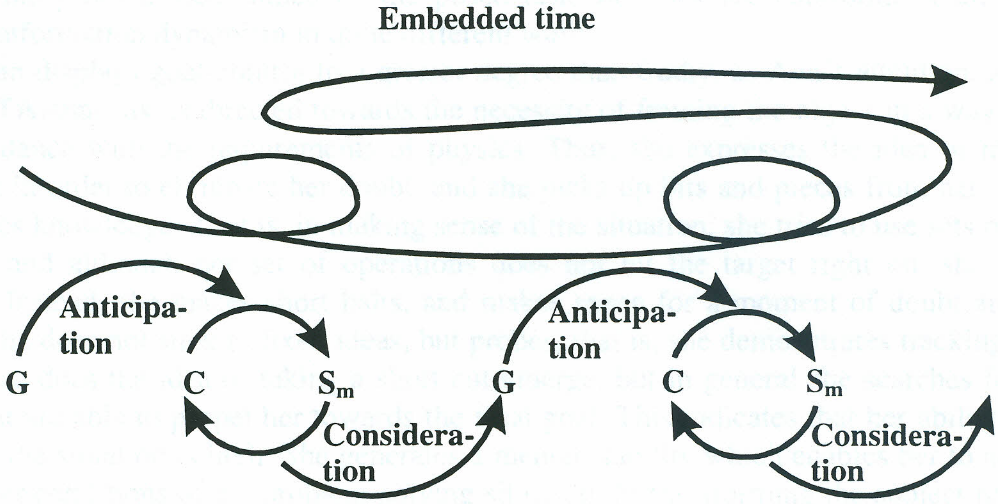
According to Prigogine and Stengers (1993), the evolution of open systems takes place in irreversible time. In irreversible time, biological systems, which are open by definition, reach stable states, that is, flow-stability (In German Fliessgleichgewicht; von Bertalanffy, 1950.). However, the $(G \equiv (C \equiv S_m))$-unity is not only an open system, but an open generative system in which the $(C \equiv S_m)$ components, by means of the anticipation/consideration function, are transformed by the generator position. The $(C \equiv S_m)$ components (i.e., the construction of ideas) are embedded in the $(G \equiv (C \equiv S_m))$-unity in such a way that the ideas from the vantage point of the generator position can be posited in the future as well as in the past. Therefore, a bounded time-space, in which the $(G \equiv (C \equiv S_m))$-unity by means of ideas is able to reach forward and backward without moving forward or backward, must exist. This bounded time component of the time-space relationship is called 'embedded time', which is a kind of time pocket where irreversible time is momentarily suspended. In embedded time, the $(G \equiv (C \equiv S_m))$-unity can handle the future and the past in a sort of 'here-and-now time'. This supposition implies that it is possible to assemble ideas continuously into coherent sense making structures. Thus, in embedded time, by means of ideas which pick up the configurations embedded in the transformation/information dynamism, the $(G \equiv (C \equiv S_m))$-unity is able to create sense making structures, and by doing so, the unity is able to create and sustain stability in a complex situation. In other words, in embedded time, the person creates a self and reality conception (i.e., meaning; Elstrup Rasmussen, 1980), which makes it possible for the person to reduce the complexity of the situation by means of directed operations (i.e., solve problems). Figure 6 illustrates the unfolding of the $(G \equiv (C \equiv S_m))$-unity in embedded time.

In Figure 6, the folded line illustrates that the generator position is able to posit the past as well as the future by means of ideas, and to assemble ideas into stable mental structures (i.e., meaning). These are the structures which can be reconstructed and described by Pertex.

The stable mental structures are generated by ideal operations, which means that problem-solving capabilities, that is, sets of operations - called qualifications - are embedded in the unfolding of competence. In making sense of a complex situation, the person utilises existing and developing sets of operations, that is, qualifications in transforming the subject matter in such a way that the complexity of the transformation/information dynamism is reduced by way of order.

In order to maintain the concept of embedded time as the space for returning, that is, oscillating activity, it is necessary to introduce the concept of memory as a sort of system dynamic recycling mechanism. To be able to secure the simultaneity of the generator position and the operation, and to assemble forward and backward pointing ideas into meaning, the $(G \equiv (C \equiv S_m))$-unity must be able to function in a memory space which gives substance to embedded time.

Figure 6. Unfolding of the (G ≡ (C ≡ S_m))-unity in embedded time



Embedded time also introduces a second memory dependant quality of the (G ≡ (C ≡ S_m))-unity, that of the event. In physics, the world lines of development are either continuous or discontinuous. In sense making systems, the world lines of development encompass a start, an ending, and something in between, that is, events. The event develops in embedded time as an oscillating irreversible forward and backward moving competence determined sense making process in which the person solves problems in an operational way.

The unfolding of competence takes place in the form of text production, written or spoken. Because the person is only able to speak and write in irreversible time, the oscillating movements of sense making in embedded time must be transformed into linear organised text strings. This means that the forward and backward moving sense making process has to be transformed into a text string in which the just said anticipates something which has not yet been considered, and concurrently, what is anticipated just now grasps what has already been considered. By analogy, sense making can be compared to a hidden sheet which is covered by a visible line. The line symbolises the text string and the sheet symbolises the mental structure. Although sense making and text production take place concurrently and interactively, the string will, irrespective of its compactness, never cover the hidden sheet completely, but it is possible to get a conception of the sheet on the basis of the visible compact line. Using Pertex, it is possible to reconstruct the mental structure on the basis of the text string.

As mentioned above, qualifications, that is, sets of operations, are embedded in competence. The sets of operations are, contrary to the mental structure, directly observable in the texture of the text string. For example, in the text 'the farming trainee must chop the wood on the block with an axe for the winter', the operation encompassing a farming trainee who integrates wood and axe in order to get firewood for the winter is visible, although the structure carrying the operation is hidden. However, without knowledge of the mental structure which carries the operation, the problem-solving capabilities of the person, that is, his or her qualifications, make no sense.

Ann's and Cathy's problem-solving processes

It is now (about) time to return to Ann and Cathy. The two students are both involved in solving the problem determined by the posed task, but they are controlling their transformation-information dynamism in quite different ways.

Ann displays goal-control to a greater degree than Cathy, as Ann's attention, according to the PTA-analysis, is directed towards the necessity of framing the object in a way which is in accordance with the requirements of physics. Thus, she expresses the idea of measuring qualities in order to eliminate her doubt, and she picks up bits and pieces from her repertoire of physics knowledge. That is, in making sense of the situation, she tries to use sets of qualifications, and although her set of operations does not hit the target right on, she does not despair. Instead, she makes short halts, and makes space for a moment of doubt and uncertainty. She does not stick to fixed ideas, but probes, that is, she demonstrates tracking control. Only once does the idea of taking a short cut emerge, but in general she searches for operations that are able to propel her towards the final goal. This indicates that her ability to make sense of the situation is high. She generates a mental stability which enables her to accept the non-linear conditions of the problem-solving situation. In transforming the subject matter, the information flow changes in an unpredictable way, contradictions and new problems arise en route, which puts pressure on the mental stability, and by that, the feeling of being in control. By sustaining a high level of competence, she is able to maintain her mental stability and shift her strategy in accordance with the changes of the information flow.

This is directly observable when Ann and Cathy experience an unforeseen problem when they realise that the idea of inverse proportionality between 'thickness' and 'resistance' is wrong. The concept of proportionality has been the guiding idea for a while, and therefore the new conflict between 'thickness' and the data, brought about by measurements, shakes their confidence in their hitherto comprehension. However, Ann does not shift her strategy. She becomes involved in the conflict, of course, but she does not forget the overall goal. On the contrary, she is capable of launching an offensive towards the local conflict. She searches for a new idea which can work as a new problem-solving model. This conflicting situation clearly illustrates the unity of anticipation and consideration which emerges in imbedded time. On the one hand, Ann is ready to reject the first conception of the problem as an expression of a pseudo-order. On the other hand, she is also capable of maintaining her original conception in order to be able to investigate in what respect this order is 'pseudo'. Thus, anticipation calls for consideration and consideration acquires new possibilities because of anticipation. Because of the enactment of the subject matter, that is transformation, the information flow changes, and new sides of the subject matter are perceived. This means, of course, that the feeling of ruggedness increases, and if the subject because of the growing complexity is unable to maintain stability by way of competence, efficacy may decrease. However, this does not happen for Ann, on the contrary. The intensification of the information flow increases the complexity, but for Ann, it is a necessary step towards the final reduction of complexity. This reduction occurs when she realises that it is utterly confusing to utilise the idea of 'thickness' when talking about a cross section, the idea of 'area' has to be considered. At that specific moment, the transformation takes place, and the information flow changes. Given the insight embedded in the idea of 'area', Ann's tracking control improves instantaneously, because the 'area-idea' makes a set of familiar qualifications available, which improves her mental stability in the face of complexity. Ann makes sense in the complex situation, and reduces the complexity in the transformational shift from 'thickness' to 'area'. In other words, the transformation increases the complexity momentarily, but because of the increased complexity, it is possible to pick up hitherto unperceived information, and thus she is capable of reducing the

complexity, that is, solve the problem. In that respect, she thrives on the complexity, but not just any complexity. She is in control of the rise and fall of complexity by being busy with the subject matter.

Posited as a sidekick, Cathy does not display the same degree of goal-control. Or maybe more correctly, her goal-control is shifting, probably because she is not solely directed towards the posed task. She somehow uses the task and Ann's ideas as a way of staying in the game as a social integrator. Because her position does not constitute a real problem, apparently, she is now and again able to venture into the process of solving the problem determined by the posed task. However, where Ann is able to make space for doubt and uncertainty, and vary the degree of complexity, Cathy tries to sustain stability. She holds on to known propositions, which she repeats and enlarges before jumping to new positions, in order to return to the original point of departure, whenever the complexity seems to rise. Presumably, she sustains the idea of repetition in order to stay secure. She does not experience high-end goal-control in relation to the task, but she does not strive for it either.

Only once do Ann and Cathy behave in the same way towards the task. The situation arises when both students enact the subject matter by drawing two wires – one thick and one thin – and start to compare. In that situation, Cathy suddenly perceives the posed task as subject matter, and starts to act as the constructor. She is the first to try to formulate a hypothetical relationship, saying 'each time the one gets two times smaller'. However, contrary to Ann, Cathy does not try to relate the local problem to the overall problem. She is entirely engaged in this specific transformation, and not viewing it from any change in perspective, which she – as a sidekick – entrusts Ann to do. Ann acts the part by steering her attention towards the necessity of finding a mathematical formula for the area of a circle. Thus, Ann is the one who carries out the final conceptual change from 'the thickness of the wire' to 'the area of the circle'. After the transformation, Cathy resumes her role as a sidekick, thus, her goal-control, that is, her experience of closing in on a solution, is still dependent upon Ann's goal-control. She now and again positions herself in the small group, but as Ann apparently does not contest her position as an integrator, the social situation does not constitute a problem. That is, there is little or no difference between transformation and information flow in relation to the social situation. To keep her position in the group, it is sufficient for Cathy to show her interest in the task by repeating suggestions already proposed by others. Quite frankly, if Cathy tried to solve the problem, she would, presumably, be forced to compete with Ann, which would imply that the complexity of the situation would exceed Cathy's ability. She would lose ruggedness-control, and in consequence be unable to make sense of the situation. The situation would simply be overwhelming.

Somehow, Ann is the leader. She is the one who constitutes Cathy's subject matter, which means that Cathy, in relation to the posed task, thrives on the complexity created by Ann, and not the complexity created by the posed task. And because of that, most of the time Cathy appears to echo Ann. It is only for a short while that Cathy engages herself in the posed task, that is, enacts the task as subject matter. However, in that rare moment, both Cathy and Ann aim at the feeling of progress by enacting, that is, transforming the subject matter posed by the task. Although no, or maybe just a vague overall, goal-control exists, Cathy still tries to make sure that some progress takes place. Therefore, she now and again seems to be ensuring her thrust towards progress, but because of her weak goal-control, the ensuring process becomes some sort of muddling through or even less, because she puts forward the idea of reiteration. Apparently she does not show any achievement-control at all.

Assessed in relation to what Cathy is supposed to learn in the situation, the outcome is poor. However, it is not because she is unable to cope with the posed task, but because she has

put herself in the position of a sidekick, presumably in order to avoid competition. When 'forced' out of her self-imposed position, for example when the teacher hints at the idea of 'area' instead of 'thickness', she is equally capable of enacting the posed task. This means that in order to learn by way of co-operation, she has to compete for her right to enact the subject matter defined by the posed task. In the analysed situation, she only has this right when the teacher neutralises co-operation and the competition by articulating concrete suggestions which both students are able to relate to independently. Working in groups may be productive, but it has to be based on an equal right to compete as independent persons (Elstrup Rasmussen, 1999).

Making a model of problem-solving performance

As Dörner and Wearing (1995) have shown, a variety of forms of problem-solving performance exist: 'planning', 'muddling through', 'dogmatic entrenchment' and 'aimless information collection'. These forms of performance are classes of description and not continuous categories rising from an underlying structure. In this article, it is maintained that it is possible to categorise forms of problem-solving performance on the basis of a structure generated by the non-linear interaction of the conflicting control parameters: achievement/availability and efficacy/ruggedness. However, these categories must encompass the findings of Dörner and Wearing. Looking back at the mental states of the two students, it seems as if Ann is a planner according to Dörner and Wearing. She does not take giant steps forward, but explores new ideas, and makes sure that they are fully investigated before she moves on. Cathy on the other hand seems to jump between 'entrenchment' and 'aimless information collection'. At one moment, she seems to dig in by offering the same solution repeatedly, and in the next, she seems to jump into a roaming kind of performance, where she clutches at any solution which springs to mind. If these two quite different forms of problem-solving performance are to be picked up by one and the same model, it is necessary to utilise tools of a different kind than those used by Dörner and Wearing. One of the more promising tools offered today is catastrophe theory developed by Thom (1975). "Catastrophe theory is a new method for describing the evolution of forms in nature (...) It is particularly applicable where gradually changing forces produce sudden effects (...) The theory depends upon some new and deep theorems in the geometry of many dimensions, which classify the way that discontinuities can occur in terms of a few archetypal forms (...) The remarkable thing about the results is that although the proofs are sophisticated, the elementary catastrophes themselves are both surprising and relatively easy to understand, and can be profitably used by scientists who are not expert mathematicians." (Zeemann, 1977, p.1)

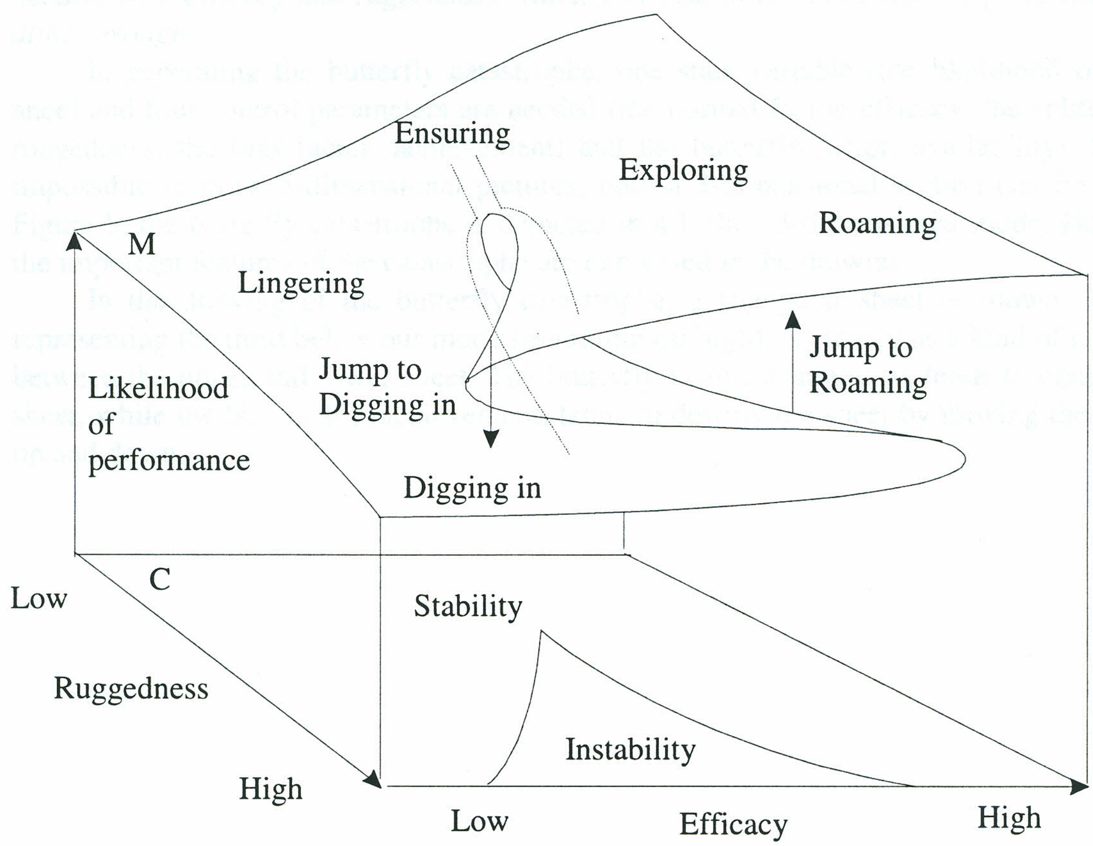
If the control parameters, achievement/availability and efficacy/ruggedness, do interact in a conflicting and non-linear way, and if the interacting control parameters give rise to relatively stable forms of performance between which sudden discontinuities can occur, it is possible to model the connection between control parameters and performance by means of a catastrophe.

The groundwork for this is a conjecture claiming that as long as the degree of ruggedness is sufficiently low, and the feeling of efficacy is of medium strength, the most likely problem-solving performance will be like that of Ann's. This kind of behaviour is called *ensuring*. The term ensuring refers to an activity the person uses to solve problems step by step, because there is a kind of balance between experienced difficulty and mastery. If the degree of efficacy grows, the person will display a certain boldness as long as the feeling of ruggedness is not too big, that is, the person will behave in an *exploring* way. The person will encounter the obstacles, but not give in to difficulties because of the feeling of efficacy. However, if the

degree of ruggedness increases to a degree where it cannot be balanced by the feeling of efficacy, the person will start *roaming*, that is, shooting off the entire arsenal of more or less suitable solutions as Cathy did. At the other end of this range of forms of problem-solving performance, the person will *linger* if the increase in ruggedness coincides with the decrease in the feeling of efficacy. And at the extreme, the person who is very low on the efficacy dimension and high on the ruggedness dimension will *dig in*, that is, again and again, the person will offer the same solution to a changing situation, like Cathy did. Thus, it is assumed that a range of forms of problem-solving performance exist: digging in, lingering, ensuring, exploring, and roaming. But, it is also assumed that the likelihood distribution of the forms of performance is two-tailed at the extremes, which means that if the feeling of ruggedness is sufficiently high, a slight change in the feeling of efficacy may result in a jump from digging in to roaming and vice versa.

If the likelihood distribution of problem-solving performance is as described, then the graph will look like the cusp-catastrophe surface (M) pictured in Figure 7 (Zeeman, 1977). According to the model, if the feeling of ruggedness and efficacy vary over the horizontal plane C, then the problem-solving performance will follow suit over the surface M above, except for the middle sheet, an inaccessible area which indicates that the performance cannot take two forms at the same time. Each point of the surface M represents an attractor of the dynamical system of sense-making, and the jumps occur when the stability of an attractor breaks down.

Figure 7. The relationship between ruggedness, efficacy and problem-solving performance modelled as a cusp-catastrophe.



The M surface shows that a continuous change in the relationship between the control parameters ruggedness and efficacy can result in a continuous change in problem-solving performance, from digging in, over lingering, ensuring and exploring to roaming. As illustrated by the dotted lines, the graph also shows that a very small difference in efficacy via an increase in ruggedness may result in quite different forms of performance (divergence). Further, the model shows that at a high level of ruggedness, with the person either digging in or roaming, a change of efficacy may result in an abrupt change of problem-solving performance, either as a jump from digging in to roaming or from roaming to digging in (catastrophes), or less dramatically from lingering to exploring and visa versa. The model shows that the same fundamental mental structure/process with quantitative variations is able to generate quite different forms of performance. Thus, in order to explain different forms of problem-solving performance, it is no longer necessary to assign different attributes to persons who perform differently in complex situations.

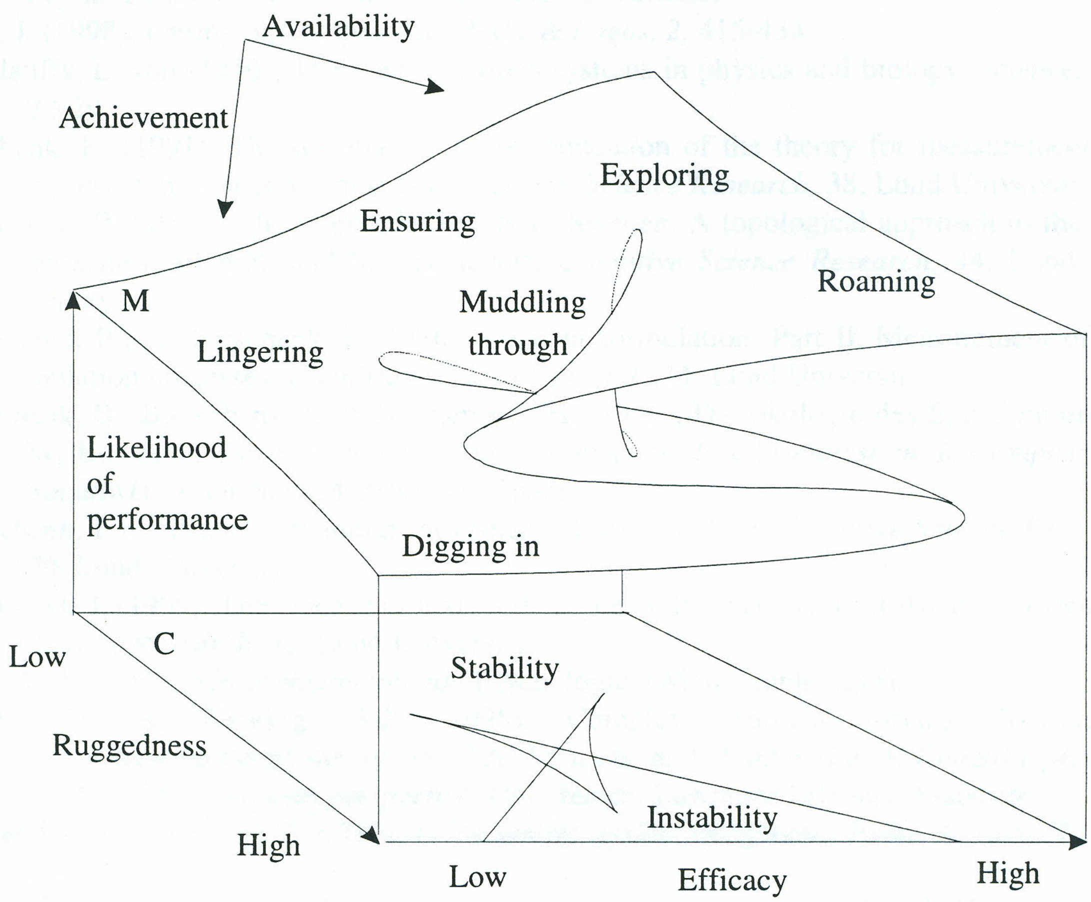
The cusp-catastrophe model depicts bimodality, illustrated by the divergence when moving from ensuring to digging in or roaming. However, as Dörner and Wearing have pointed out, a third form of problem-solving performance exists, 'muddling through', which is a kind of compromise between extremes. A third type of performance implies trimodality. "Trimodal behaviour determines the unique and much richer 5-dimensional geometry of the butterfly-catastrophe. Since trimodality often emerges out of bimodality, the natural way to analyse the butterfly is to regard it as an extension of the cusp." (Zeeman, 1977, p. 29)

The five-dimensional butterfly-catastrophe demands a four-dimensional control space. The two remaining control parameters, feeling of availability and achievement, are assumed to constitute the needed parameters. This means that it is availability and achievement in connection with efficacy and ruggedness which give rise to the third type of performance, *muddling through.*

In generating the butterfly catastrophe, one state variable (the likelihood of performance) and four control parameters are needed (the normal factor, efficacy; the splitting factor, ruggedness; the bias factor, achievement; and the butterfly factor, availability). Since it is impossible to draw 5-dimensional pictures, only a 3-dimensional section can be shown. In Figure 8, the butterfly catastrophe is depicted in a locked 3-dimensional mode. However, all the important features of the catastrophe are expressed in the drawing.

In the drawing of the butterfly catastrophe, a triangular sheet is shown. This sheet, representing the third behaviour mode (muddling through), is created as a kind of compromise between the upper and lower sheet. The butterfly factor, availability, tends to create the new sheet, while the bias factor, achievement, tends to destroy the sheet by moving the surface M up and down.

Figure 8. The catastrophe model of the relationship between order parameters and problem-solving performance.



If for example, an ensuring person for some reason experiences an increased feeling of achievement, this person (over achiever) will be pushed into the state of exploring or maybe roaming, while a decreased feeling of achievement will push the person (under achiever) towards lingering and digging in. If on the other hand, a roaming or digging-in person experiences an increased feeling of availability, a new pathway back to ensuring is opened. This path goes from roaming or digging in through a catastrophe into the state of muddling through, from which the path into ensuring is open, if the feeling of ruggedness decreases. This means that if a person is trapped between roaming and digging in, a change in the feeling of availability may move the person towards the more optimal form of performance, muddling through, which could be the jumping-off point into ensuring, if the degree of ruggedness is decreased. This model can be likened to the thinking of Vygotsky (1962), if it can be shown that the teacher's position as a more capable peer does influence the student's feeling of ruggedness and availability. However, the model of problem-solving performance shows that by means of catastrophe theory, and the ecological theory of sense making, it is at least possible to assemble the findings of Dörner and Wearing into a structural solution.

References

Bang, J. (1996), Tænkning og forståelse - en undersøgelse af gymnasieelevers lærehandlinger i fysik. Roskilde Universitetscenter. Ph.D.-dissertation.

Bang, J. (1998), Læring og kompetence. *Psyke & Logos, 2,* 415-434.

Bertalanffy, L. von (1950), The theory of open systems in physics and biology. *Science, 111,* 23-29.

Birschenk, B. (1991), The schema axiom as foundation of the theory for measurement and representation of consciousness. *Cognitive Science Research*, 38. Lund University.

Bierschenk, B. (1992), The referential reality of Sweden. A topological approach to the consciousness of high and low achievers. *Cognitive Science Research*, 44. Lund University.

Bierschenk, B., & Bierschenk, I. (1986), Concept formulation. Part II. Measurement of formulation processes. *Cognitive Science Research*, 11. Lund University.

Bierschenk, B., Bierschenk, I., & Helmersson, H. (1996), Die ökologie des Sprachraums. In: W. Bos & C. Tarnai (Eds.), *Computerunterstützte Inhaltsanalyse in den Empirischen Socialwissenschaften*. Münster: Waxmann.

Bierschenk, I. (1999), The pendular movement of text building. *Cognitive Science Research*, 70. Lund University.

Bierschenk, I. (1999), The essence of text. A dialogue on Petspective Text Analysis. *Cognitive Science Research*, 42. Lund University.

Duncker, K. (1945), *On problem-solving*. Psychological Monograph, 58(5).

Dörner, D., & Wearing, A.J. (1995), Complex problem solving: Toward a (computersimulated) theory. In: P.A. Frensch, & J. Funke (Eds.), *Complex problem solving. The European perspective*. New Jersey: Lawrence Erlbaum Associates.

Elstrup Rasmussen, O. (1980), Den menneskelige psykes idiogenese. *Psyke & logos, 2*, 113-146

Elstrup Rasmussen, O. (1994a), The discontinuity of human existence, Part I. The fundamental concepts of human existence and the relation between the singular and the super singular. *Cognitive Science Research*, 50. Lund University.

Elstrup Rasmussen, O. (1994b), The discontinuity of human existence, Part II. The general and the specific theories of discontinuity. *Cognitive Science Research*, 51. Lund University.

Elstrup Rasmussen, O. (1996), A strategy for the development of a theory of organisational leadership and administration. In: Niels Engelsted, Judy Gammelgaard, Anker H. Jørgensen, Simo Køppe, and Aksel Mortensen (Eds.), *Psychological Yearbook, University of Copenhagen (Vol. 2)*. Copenhagen: Museum Tusculanum Press.

Elstrup Rasmussen, O. (1997a), Modelling knowing systems. I: E. Lefebvre & R. Cooper (Eds.), *Uncertainty, Knowledge and Skill*. Limburg University: Belgium.

Elstrup Rasmussen, O. (1997b), Co-ordinating Co-operation in complex information flows: A theoretical analysis and empirical description of competence-determined leadership. *Cognitive Science Research,* 61. Lund University.

Elstrup Rasmussen, O. (1998), Modellering af forholdet mellem kompetence og lederskab, kvalifikationer og administration - En oversigt. *Psyke & Logos, 2,* 527-558.

Elstrup Rasmussen, O. (1999), Putting quality of life to the test. In: L. L. Yuan, B. Yuen, & C. Low (Eds.). *Urban quality of life - critical issues and options*. National University of Singapore: Singapore. 196-211.

Helmersson, H. (1992), Main principles for perspective text analysis via the PC system PER-TEX. *Cognitive Science Research,* 41. Lund University.

Kelso, J.A.S. (1997), *Dynamic patterns. The self-organization of brain and behavior.* Massachusetts: The MIT Press.

Kugler, P. N., & Turvey, M. T. (1987), *Information, natural law and the assembly of rhythmic movement.* London: Lawrence Erbaum.

March, J.G., & Simon, H.A. (1958), organizations. New York: John Wiley & Sons.

Prigogine, I, & Stengers, I. (1993), *Das Paradox der Zeit.* München: Piper.

Prigogine, I. & Stengers, I. (1985), *Den nye pagt mellem mennesket og universet.* Aarhus: ASK.

Thom, R. (1975), *Structural stability and morphogenesis: An outline of a general theory og models.* Massachusetts: Benjamin.

Vygotsky, L.S. (1962), *Thought and language.* London: John Wiley.

White, R.W. (1959), Motivation reconsidered: The concept of competence. *Psychological Review, 66(5),* 297-333.

Zeeman, E.C. (1977), *Catastrophe theory. Selected papers, 1972-1977.* Massachusetts: Addison-Wesley Publishing Company.

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